Construction and Building Materials 174 (2018) 443–455

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Toward the development of performance-related specification for bio-rejuvenators

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HIGHLIGHTS

- Effect of bio-rejuvenators on low temperature property of binder was investigated.
- Total fatty acid content is a good performance indicator of bio-rejuvenators.
- Total fatty acid content correlated better with *m*-based critical low temperature.
- It is recommended to control saturated fatty acid (or wax) content within 50%.
- A framework of performance-related specification for bio-rejuvenators is proposed.

ARTICLE INFO

Article history:
Received 13 February 2018
Received in revised form 9 April 2018
Accepted 10 April 2018
Available online 24 April 2018

Keywords:
Bio-rejuvenator
RAP
RAS
Fatty acid
Dynamic viscosity

ABSTRACT

The use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) has many benefits. However, premature cracking has become a serious concern for mixes containing RAP/RAS. Recently, a variety of bio-rejuvenators have been developed to address the premature cracking issue. However, there is no purchasing specification available for bio-rejuvenators. This paper presents the efforts made toward the development of performance-related specification for bio-rejuvenators. A total of eight bio-rejuvenators including seven commercial bio-rejuvenators and one recycled vegetable oil, were evaluated in this study. Their chemical and rheological properties and aging characteristics were measured. In addition, the effectiveness of the eight bio-rejuvenators in improving low temperature property of (recycled) asphalt binders was investigated. Although rheological dynamic viscosity has a fair correlation with the stiffness based low temperature performance grade (PG), the chemical property, total fatty acid content is the preferred performance indicator, because (1) the low temperature PG of recycled asphalt binders is controlled primarily by relaxation property (or m value); and (2) the total fatty acid content has much better correlation with the m-based low temperature PG than the dynamic viscosity. The total fatty acid content was verified by mixing pure fatty acid compounds (palmitic acid, oleic acid, and linoleic acid) with a virgin PG64-22 binder. The identified performance indicator was further confirmed by testing blends of recycled binder/virgin binder/three bio-rejuvenators. Additionally, two field test sections with 30% recycled RAP and bio-rejuvenators were constructed for validation. Laboratory test results of the plant mixes collected from the field clearly validated the effectiveness of total fatty acid content as the performance indicator for bio-rejuvenators. At the end of this paper, a framework of performance-related specification for bio-rejuvenators is proposed. A total of seven aspects of bio-rejuvenators are included: (1) total fatty acid content for bio-rejuvenator classification, (2) saturated fatty acid content for avoiding potential negative effect of wax, (3) flashing point for safety, (4) dynamic viscosity for pumping bio-rejuvenators to the mixing drum, (5) dynamic viscosity ratio of RTFO residue to original rejuvenator for screening out the bio-rejuvenators susceptible to short term aging, (6) RTFO (or TFO) mass loss for avoiding massive loss of volatiles, and (7) specific gravity.

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https://doi.org/10.1016/j.conbuildmat.2018.04.093
0950-0618/

1. Introduction

The asphalt industry has a long history of using reclaimed asphalt pavements (RAP) and recycled asphalt shingles (RAS) in asphalt mixes [1]. In 2013, over 1 million tons of RAP and 150,000 tons of RAS were used in Texas alone [2]. In the last several years, the use of RAP and RAS has become a new norm. They not only reduce the construction cost and increases rutting resistance of asphalt mixes but also improve sustainability by aiding in the reduction of greenhouse gas emissions. Additionally, adding RAS into asphalt mixes also conserves valuable landfill space. However, recycled binders from both RAP and RAS are often severely aged and substantially stiffer than regular virgin binders. Consequently, it often leads to a stiffer mix with relatively lower resistance to cracking, which is one of the major concerns with the use of RAP and RAS in asphalt mixes.

One of the approaches addressing the premature cracking issue of RAP/RAS mixes is to use rejuvenators or recycling agents [2]. The purpose of using rejuvenator is to 1) restore the aged asphalt characteristics to a consistency level appropriate for construction purposes and for the end use of the mixture; 2) restore the aged asphalt to its optimal chemical characteristics for durability, and 3) provide sufficient additional binder to coat new aggregate and to satisfy mix design requirements [1]. In late 1970s and early 1980s substantial research efforts were made on rejuvenators [1,3–6]. One of the research outcomes was ASTM D4552: Standard Practice for Classifying Hot-Mix Recycling Agent [7], as shown in Table 1. The rejuvenators (or recycling agent) are classified into six grades (or groups) mainly through viscosity measured at 60 °C (140 °F). The smaller the viscosity, the more effective is the rejuvenator. These traditional rejuvenators are either softer asphalt binders (such as AC 1.5) or some extracts from petroleum (such as aromatic oils, paraffinic oils, and naphthenic oils).

Over the years many new rejuvenators have been developed and used in the field projects. Different from the traditional petroleum-based rejuvenators, the new rejuvenators are derived from bio-products. But not much work has been done in identifying a performance indicator for bio-rejuvenators. Limited work previously done by the authors clearly indicated that the existing specification ASTM D4552-10 may not be suitable for these new bio-rejuvenators [2]. For example, the viscosities of some bio-rejuvenators at 60 °C are smaller than 50 mm^2/s. Furthermore, the data presented later shows that viscosity itself is not a good performance indicator for bio-rejuvenators, although it is important for pumping the rejuvenators into the asphalt plant during production. Thus, it is necessary to characterize these bio-rejuvenators and identify a performance indicator on which future specification will be built.

Clearly, the use of rejuvenators and associated specifications need to be updated to reflect the new bio-rejuvenators and today's performance grade (PG) binder testing as well as other new chemical analysis tests. To achieve this main objective, the following steps were undertaken by the researchers;

- Characterize chemical, rheological, and aging properties of bio-rejuvenators,
- Identify the performance indicator of bio-rejuvenators through binder blending and associated PG testing,
- Validate the performance indicator through binder/compound blending,
- Validate the performance indicator through field test sections, and
- Propose a performance-related specification framework for bio-rejuvenators.

Details of each of these steps are presented below. A summary and conclusions are presented at the end of the paper.

2. Bio-rejuvenator characterization: rheological, chemical, and aging characteristics

Before discussing laboratory tests and associated results, this section presents some background information about bio-rejuvenators.

2.1. Bio-rejuvenators

Oxidation makes asphalt binders stiffer during production and construction, and in the following service years through aging. During the oxidative aging process, an irreversible chemical reaction with oxygen changes the molecular structure of the binder, which also leads to changes in rheological properties of asphalt binders (such as a much lower phase angle). Correspondingly, asphalt binder is stiffened and its ability to flow is reduced. To restore the flow ability and the phase angle of aged asphalt binder, a variety of bio-rejuvenators have been developed in recent years. Different from traditional petroleum-based rejuvenators, the bio-rejuvenators have a common component: fatty acid (or lipid). A fatty acid is a carboxylic acid with an aliphatic chain with aliphatic tails of 13–21 carbons [17]. Fatty acids without carbon-carbon double bonds are known as saturated; those with double bonds called as unsaturated. Unsaturated fatty acids are further categorized as monounsaturated (having one double bonds) and polyunsaturated (having more than one double bonds). As shown later, the amount of fatty acid directly impacts the performance of the bio-rejuvenators.

Table 1
Physical properties of hot-mix recycling agents (ASTM D4552-10) [7].

Test	ASTM Method	RA1	RA5	RA25	RA75	RA250	RA500
Viscosity, 60 °C, mm^2/s (cSt)	D2170 [9] or D2171 [10]	50–175	176–900	901–4500	4501–12,500	12,501–37,500	37,501–60,000
Flash Point, COC, °C [°F]	D92 [11]	219 [425]	219 [425]	219 [425]	219 [425]	219 [425]	219 [425]
Saturates, Wt%	D2007 [12]	Max. 30	Max. 30	Max. 30	Max. 30	Max. 30	Max. 30
Tests on Residue from RTFO or TFO oven 163 °C							
1) Viscosity ratio*	D2872 [13]	Max. 3	Max. 3	Max. 3	Max. 3	Max. 3	Max. 3
2) Wt. Change, %	or D1754 [14]	Max. 4	Max. 4	Max. 3	Max. 3	Max. 3	Max. 3
Specific Gravity	D70 [15] or D1298 [16]	Report	Report	Report	Report	Report	Report

Note: *Viscosity ratio = viscosity of residue from Rolling Thin-Film Oven (RTFO) or Thin-Film Oven (TFO) Test/Original Viscosity.